2021

Industrial and Systems Engineering

Body of Knowledge

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Foreword

The effort to accumulate the Industrial and Systems Engineering Body of Knowledge represents the work of several volunteers from the Institute of Industrial and Systems Engineers, whose contributions are valued and appreciated. Notable credits to Krishnan Krishnaiyer for the design of the Industrial and Systems Engineering Body of Knowledge logos and editorial assistance.

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Introduction

Industrial Engineering (I.E.) is concerned with the design, improvement, and installation of integrated systems of people, materials, information, equipment, and energy. It draws upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results typically obtained from such systems. The Body of Knowledge associated with Industrial Engineering is as broad and varied as the Industrial Engineering profession itself., like any other engineering discipline, requires a fundamental knowledge of math and science. These include Calculus, Statistics, Probability, Chemistry, Physics, and Engineering Sciences. The underlining assumption is that anyone wishing to gain proficiency in Industrial Engineering already possesses a fundamental background in basic math and science. This document represents a repository of essential information for Industrial Engineers (I.E., 's). The Industrial and Systems Engineering Body of Knowledge defines a taxonomy of relevant, I.E., concepts.

There are fourteen (14) knowledge areas in the Industrial and Systems Engineering Body of Knowledge (IISEBoK). An outline represents each knowledge area —Industrial and Systems Engineering Body of Knowledge defines what needs to be known to achieve mastery in the field. A list of references is included in each knowledge area providing the reader with a resource to the requisite detail necessary to obtain a mastery of the areas provided in the Industrial and Systems Engineering Body of Knowledge . Many of these knowledge areas contain an overlap of content. Every effort has been made to place content in the knowledge area that best represents the use of that knowledge. References are made between knowledge areas where the overlap is identified. The Industrial and Systems Engineering Body of Knowledge is structured around the fundamental knowledge areas within I.E.

Applications of the Industrial and Systems Engineering Body of Knowledge are an extension of how the I.E. knowledge areas are employed in the design, improvement, and installation of integrated systems of people, materials, information, equipment, and energy. As such, specific details of how the Industrial and Systems Engineering Body of Knowledge is used in health care, banking, electronics manufacturing, or any other specific industry are not provided. Instead, the Industrial and Systems Engineering Body of Knowledge offers the knowledge areas necessary for the design, improvement, and installation of integrated systems of people, materials, information, equipment, and energy in any industry or service area.

Industrial and Systems Engineering Body of Knowledge

1 Work Design and Measurement

Work Design and Measurement covers the tools and techniques used to establish the time for an average worker to carry out a specified task at a defined level of performance in a defined work setting. The analysis associated with Work Design and Measurement focuses on creating a standardized work environment that maximizes worker satisfaction and creates the best possible value for the enterprise and its customers.

1.1 Uses of Standards

- 1.1.1 Uses of standards and methods for setting standards
- 1.1.2 The role of standards as management information
- 1.1.3 Use of production studies
- 1.1.4 Reduce product cost using standards

1.2 Time and Motion Study

- 1.2.1 Number of necessary observations
- 1.2.2 Time study elements
  - 1.2.2.1 Continuous
  - 1.2.2.2 Snapback
- 1.2.3 Performance rating
- 1.2.4 Allowances
- 1.2.5 Standard time
- 1.2.6 Production rates
- 1.2.7 Efficiency and utilization

1.3 Predetermined Time Systems

- 1.3.1 MTM variations
- 1.3.2 MOST
- 1.3.3 Creating standard data

1.4 Work Sampling

- 1.4.1 Theory of sampling
- 1.4.2 Number of observations and frequency
- 1.4.3 Use of control charts in work sampling

1.5 Learning Curve

1.6 Line Balancing

1.7 Service Applications

1.8 Use with Labor and Unions

1.9 Workstation Design

1.9.1 Worker Capacity Analysis

1.9.1.1 Left hand-right hand

1.9.1.2 Multiple activity

1.9.1.3 Work distribution chart

1.9.2 Analysis Tools

1.9.2.1 Operations process charts

1.9.2.2 Flow process charts

1.9.2.3 Worker and machine process charts

1.9.2.4 Job standard sheets

1.9.2.5 Labor variance reporting

1.9.3 Job Analysis

1.9.3.1 Job descriptions

1.9.3.2 Job evaluation

1.10 Wage Surveys

REFERENCES:

Work Systems and Methods, Measurement and Management of Work. Groover, Mikell P. Prentice Hall. 2007.

2 Operations Research and Analysis

Operations Research and the Management Sciences include a variety of problem-solving techniques focused on improved efficiency of systems and support in the decision-making process. The realm of Operations Research involves the construction of mathematical models that aim to describe and/or improve real or theoretical systems and solution methodologies to gain real-time efficiency. The knowledge area of Operations Research is by its nature mathematical and computational. A fundamental basis in this knowledge area includes probability, statistics, calculus, algebra, and computing.

2.1 Operations Research

- 2.1.1 Modeling approaches
- 2.1.2 Heuristic versus optimization procedures

2.2 Linear Programming (LP)

- 2.2.1 LP applications
  - 2.2.1.1 Diet problem
  - 2.2.1.2 Work scheduling
  - 2.2.1.3 Capital budgeting
  - 2.2.1.4 Blending problems
- 2.2.2 LP modeling techniques
- 2.2.3 LP assumptions
- 2.2.4 Simplex method
- 2.2.5 Degenerate and unbounded solutions
- 2.2.6 Post-optimality and sensitivity analysis
- 2.2.7 Interior-point approaches
- 2.2.8 Duality theory
- 2.2.9 Revised simplex method
- 2.2.10 Dual simplex method
- 2.2.11 Parametric programming
- 2.2.12 Goal programming

2.3 Transportation Problem

2.3.1 Transportation model and its variants

2.3.2 Transportation simplex method

2.3.3 Transshipment problems

2.4 Linear Assignment Problem

2.4.1 Assignment model

2.4.2 The Hungarian algorithm

2.5 Network Flows and Optimization

2.5.1 Shortest path problem

2.5.2 Minimum spanning tree problem

2.5.3 Maximum flow problem

2.5.4 Minimum cost flow problem

2.5.5 CPM and PERT problems

2.5.6 Network simplex method

2.6 Deterministic Dynamic Programming

2.6.1 Applications

2.6.1.1 Knapsack/fly-away/cargo-loading problems

2.6.1.2 Workforce size problems

2.6.1.3 Equipment replacement problems

2.6.1.4 Investment problems

2.6.1.5 Inventory (see Operations Engineering & Management)

2.6.2 Forward and backward recursions

2.7 Integer Programming

2.7.1 Applications and modeling techniques

- 2.7.1.1 Capital budgeting
- 2.7.1.2 Set-covering and set-partitioning problems
- 2.7.1.3 Fixed-charge problem
- 2.7.1.4 Either-or and if-then constraints
- 2.7.1.5 Branch-and-bound algorithm
- 2.7.1.6 Cutting plane algorithm
- 2.7.1.7 Traveling salesman problem and solution methods

2.8 Nonlinear Programming

2.8.1 Unconstrained algorithms

- 2.8.1.1 Direct search methods
- 2.8.1.2 Gradient methods

2.8.2 Constrained algorithms

- 2.8.2.1 Separable programming
- 2.8.2.2 Quadratic programming
- 2.8.2.3 Chance-constrained programming
- 2.8.2.4 Linear combinations method

2.9 Metaheuristics

2.9.1 Steepest ascent and descent (Greedy algorithms)

2.9.2 Tabu search

2.9.3 Simulated annealing

2.9.4 Genetic algorithms

2.9.5 Ant colony optimization

2.9.6 Particle swarm techniques

2.10 Decision Analysis and Game Theory

2.10.1 Multi-criteria decision making

2.10.2 Decision making under certainty

2.10.2.1 Analytic hierarchy process

2.10.2.2 ELECTRE

2.10.3 Decision making under risk and uncertainty

2.10.3.1 Decision tree-based expected value criterion

2.10.3.2 Utility theory

2.10.4 Two-person zero-sum and constant-sum games

2.10.5 Robust decision making

2.11 Modeling Under Uncertainty

2.11.1 Stochastic processes

2.11.2 Markov chains

2.11.3 Chapman-Kolmogorov equations

2.11.4 States and properties

2.11.5 Stochastic programming

2.12 Queuing Systems

2.12.1 Components of a queuing model

2.12.2 Relationship between the exponential and Poisson distributions

2.12.3 Birth-and-death process-based queuing models

2.12.4 Queuing models involving non-exponential distributions

2.12.5 Priority-discipline queuing models

2.12.6 Queuing networks

2.13 Simulation

2.13.1 Monte Carlo simulation

2.13.2 Continuous and discrete time models

2.13.3 Simulation methodology

2.13.3.1 Sampling from probability distributions

2.13.4 Random number generation

2.14 Fundamentals of Systems Dynamics

2.14.1 Principles of systems dynamics

2.14.2 Balancing loops

2.14.3 Feedback loops

REFERENCES:

Introduction to Operations Research. Hillier, Frederick S. and Lieberman, Gerald J. McGraw-Hill, 10th Edition. 2015.

Operations Research: An Introduction. Taha, Hamdy A. Prentice Hall, 9th Edition. 2011.

Engineering Decision Making and Risk Management. Herrmann, Jeffrey, W. John Wiley & Sons, 2015.

Dynamic Programming. Bellman, Richard. Princeton University Press, 2010.

Markov Decision Processes: Discrete Stochastic Dynamic Programming, Puterman, Martin L., Wiley Series in Probability and Statistics, 1st Edition, 2005.

Introduction to Probability Models. Ross, Sheldon, M. Academic Press, 11th Edition, 2014.

Fundamentals of Queuing Theory, Gross, D., Shortle, John F., Thompson, James M. and Harris, Carl M, Wiley-Interscience, 4th Edition, 2008.

Discrete-Event System Simulation. Banks, Jerry, Carson, II, John S. Nelson, Barry L. and Nicol, David M. Prentice Hall, 5th Edition. 2010.

Multiobjective Analysis with Engineering and Business Applications. Goicoechea, Ambrose, Hansen, Don R. and Duckstein, Lucien. John Wiley & Sons. 1982.

Principles of Systems. Forrester, Jay W. Wright-Allen Press. 1968.

Introduction to Linear Optimization. Bertsimas, Dimitris and Tsitsiklis, John N. Athena Scientific. 1997.

Linear Programming and Network Flows, 4th Edition. Bazaraa, Mokhtar S., Jarvis, John J., Sherali Hanif D. Wiley. 2009.

Integer and Combinatorial Optimization. Wolsey, Laurence A., and Nemhauser, George L. Wiley. 1999.

Integer Programming. Conforti, Michele, Cornuejols, Gerard, and Zambelli, Giacomo. 2014.

Nonlinear Programming, 3rd Edition. Bertsekas, Dimitri P. Athena Scientific. 2016.

Linear and Nonlinear Programming, 4th Edition. Luenberger, David G. and Ye, Yinyu. Springer. 2016.

Network Flows: Theory, Algorithms, and Applications. Ahuja, Ravindra K., Magnanti, Thomas L., Orlin, James B. Pearson. 1993.

3 Engineering Economic Analysis

Engineering Economics is a specific knowledge area of economics focused on engineering projects. Industrial engineers need to understand economic viability of any potential problem solution.

3.1 Value and Utility

- 3.1.1 Understand the difference between value and utility in economics
- 3.1.2 Understand relationship between value and utility and its importance in economics

3.2 Classification of Cost

- 3.2.1 Understand costs to properly compare engineering alternatives
- 3.2.2 First cost
- 3.2.3 Fixed and variable cost
- 3.2.4 Incremental and marginal cost
- 3.2.5 Sunk cost

3.3 Interest and Interest Formulas

- 3.3.1 Time value of money
- 3.3.2 Equivalence involving interest

3.4 Cash Flow Analysis

- 3.4.1 Present worth
- 3.4.2 Annual equivalent
- 3.4.3 Future worth
- 3.4.4 Capitalized worth
- 3.4.5 Benefit-cost ratio
- 3.4.6 Payback periods
  - 3.4.6.1 Payback period
  - 3.4.6.2 Discounted payback period
- 3.4.7 Rate of returns
  - 3.4.7.1 Internal rate of return
  - 3.4.7.2 External rate of return

3.5 Financial Decision Making Among Alternatives

- 3.5.1 Proposal types
- 3.5.2 Decision criteria for alternatives
- 3.5.3 Decision criteria under limited funds
- 3.5.4 Methods
- 3.5.5 Ranking methods
  - 3.5.5.1 Present worth
  - 3.5.5.2 Annual worth
  - 3.5.5.3 Future worth
  - 3.5.5.4 Capitalized worth
- 3.5.6 Incremental method
  - 3.5.6.1 Internal rate of return (IRR)
  - 3.5.6.2 External rate of return (ERR)
  - 3.5.6.3 Benefit-cost ratio

3.6 Replacement Analysis

- 3.6.1 Decision criteria for making replacement decisions
- 3.6.2 Determining the economic life of an asset

3.7 Break-Even and Minimum Cost Analysis

- 3.7.1 Evaluating two alternatives
- 3.7.2 Evaluating multiple alternatives

3.8 Evaluation of Public Activities

- 3.8.1 General welfare of public interests
- 3.8.2 Financing public activities
- 3.8.3 Benefit-cost analysis
- 3.8.4 Identifying benefits, dis-benefits, and cost

3.9 Accounting and Cost Accounting

- 3.9.1 General accounting
- 3.9.2 Cost accounting
- 3.9.3 Allocation of overhead

3.10 Depreciation and Depreciation Accounting

- 3.10.1 Types of depreciation
- 3.10.2 Consuming assets
- 3.10.3 Depreciation methodologies
- 3.10.4 Depletion
- 3.10.5 Capital recovery

3.11 Income Taxes in Economic Analysis

- 3.11.1 Profit and income taxes
- 3.11.2 Individual income taxes
- 3.11.3 Corporate income taxes
- 3.11.4 Depreciation and income taxes
- 3.11.5 Depletion and income taxes

3.12 Estimating Economic Elements

- 3.12.1 Cost estimating methods
- 3.12.2 Service life estimation
- 3.12.3 Judgment in estimating

3.13 Estimates and Decision Making

- 3.13.1 Estimating economic benefits
- 3.13.2 Judgments in estimating

3.14 Decision Making Involving Risk

- 3.14.1 Probabilistic methods related to decision making
- 3.14.2 Decision trees

3.15 Decision Making Under Uncertainty

- 3.15.1 Methods related to decision making in the absence of meaningful data
- 3.15.2 Payoff matrix
- 3.15.3 Laplace rule
- 3.15.4 Maximin and maximax rules
- 3.15.5 Hurwicz rule
- 3.15.6 Minimax regret rule

3.16 Analysis of Construction and Production Operations

- 3.16.1 Critical path (see Operations Engineering & Management)
- 3.16.2 Geographic location
- 3.16.3 Economic operation of equipment
- 3.16.4 Variable demand

REFERENCES:

Engineering Economy. Sullivan, William G., Wicks, Elin M., and Koelling, C. Patrick. Prentice-Hall, 16th Edition. 2014.

Engineering Economic Analysis. Newnan, Donald G., Lavelle, Jerome P., and Eschenbach, Ted G. Oxford University Press, 12th Edition. 2013.

Fundamentals of Engineering Economic Analysis. White, John A., Grasman, Kellie S., Case, Kenneth E., Needy, Kim L., and Pratt, David B. Wiley, 1st Edition. 2013.

Contemporary Engineering Economics. Park, Chan S. Pearson, 6th Edition. 2015.

Engineering Economy. Blank, Leland, and Tarquin, Anthony. McGraw-Hill, 7th Edition. 2011.

4 Facilities Engineering and Energy Management

Facilities Engineering is concerned with the arrangement of physical resources to support the optimal production and distribution of goods and services. Energy Management includes the planning and operation of energy required in facilities to support the production and distribution of goods and services. Their close interrelationship accounts for their knowledge topic described in a common section.

4.1 Facilities Location

4.1.1 Single-facility placement

4.1.2 Multiple-facility placement and tradeoffs with a single facility

4.1.3 Location-allocation problems

4.1.4 Global facilities

4.2 Facilities Sizing

4.2.1 Customer demand/market analysis/inventory implications

4.2.2 Product, process, and schedule analysis

4.2.3 Equipment selection and requirements analysis

4.2.4 Personnel requirements analysis

4.2.5 Space requirements analysis

4.2.5.1 Workstations

4.2.5.2 Storage

4.2.5.3 Departments

4.2.5.4 Aisles

4.2.5.5 Offices

4.3 Facilities Layout

4.3.1 Basic layout types

4.3.1.1 Applications

4.3.1.2 Advantages

4.3.1.3 Disadvantages

4.3.2 Data requirements

4.3.3 Traditional approaches

4.3.3.1 Systematic layout planning

4.3.3.2 Flow process chart
4.3.3.3 Activity relationship chart
4.3.3.4 From-to chart
4.3.3.5 Distance measures

4.3.4 Basic algorithms

4.3.4.1 Construction
4.3.4.2 Improvement
4.3.4.3 Hybrid

4.3.5 Americans with Disabilities Act

4.3.6 Evaluation of alternative layouts

4.4 Material Handling

4.4.1 Material handling principles
4.4.2 Unit of measure
4.4.3 Equipment types and selection
4.4.4 Models for material handling system design

4.5 Storage, Warehousing, and Distribution

4.5.1 Storage/warehouse/distribution functions
4.5.2 Storage policies
4.5.3 Order picking methods and design principles
4.5.4 Analytical models of order picking functions
4.5.5 Storage/retrieval equipment and systems
4.5.6 Location and layout of docks
4.5.7 Design for racks and block stacking
4.5.8 Warehouse layout models

4.6 Plant and Facilities Engineering

4.6.1 Building codes compliance and use of standards
4.6.2 Structural systems
4.6.3 Atmospheric systems
4.6.4 Enclosure systems
4.6.5 Lighting and electrical systems

4.6.6 Life safety systems

4.6.7 Security and loss control systems

4.6.8 Sanitation systems

4.6.9 Building automation systems

4.6.10 Facilities maintenance management systems

REFERENCES:

Facilities Planning. Tompkins, James A., White, John A., Bozer, Yavuz A. and Tanchoco, J. M. A. Wiley, 4th Edition. 2010.

Facilities Design. Heragu, Sunderesh S. CRC Press, 4th Edition. 2016.
Energy Management Handbook. Doty, Steve and Turner, Wayne C. CRC Press, 5th Edition. 2004.

5 Quality & Reliability Engineering

Quality Engineering covers the tools and techniques employed in manufacturing and service industries. In product manufacturing, these techniques help prevent mistakes or defects in products. In service processes, these tools are used to avoid problems when delivering solutions or services to customers. A closely related knowledge area is Reliability Engineering. These concepts are used to determine the ability of a system or component to function under stated conditions for a specified period.

5.1 Quality Definition and Fundamentals

5.1.1 Quality Concepts

5.1.1.1 Design for quality

5.1.1.2 Manufacturing quality

5.1.1.3 Marketing/service quality

5.1.2 Fundamentals

5.1.2.1 Probability

5.1.2.2 Sample data

5.1.2.3 Distributions

5.1.2.4 Basic statistics

5.1.2.5 Hypothesis testing

5.1.2.6 Analysis of variance

5.1.2.7 Regression analysis

5.1.2.8 Histogram, box plot and probability plot

5.2 On-line Quality Engineering Methods

5.2.1 Control Charts and Process Capability

5.2.1.1 Variable control charts

5.2.1.2 $\overline{X}$- chart

5.2.1.3 R-chart

5.2.1.4 S-chart

5.2.1.5 S^2-chart

5.2.1.6 Exponentially weighted moving average (EWMA) chart

5.2.1.7 Cumulative sum control (CUSUM) chart

5.2.1.8 Moving range (MR) chart

5.2.1.9 Multivariate control chart

5.2.1.10 Single stage production processes

5.2.1.11 Multi-stage production processes

5.2.1.12 Attribute control charts

5.2.1.13 Fraction defective (p-chart, np-chart)

5.2.1.14 Number of defects per unit (c-chart, u-chart)

5.2.1.15 CUSUM chart

5.2.1.16 EWMA chart

5.2.2 Lot Acceptance Sampling

5.2.2.1 Attributes

5.2.2.2 Single-sample plans

5.2.2.3 Double and sequential fraction-defective sampling

5.2.2.4 Multiple fraction-defective

5.2.2.5 DoD sampling plans

5.2.2.6 Variables

5.2.2.7 Fraction defective

5.2.2.7.1.1 Standard deviation known

5.2.2.7.1.2 Standard deviation unknown

5.2.2.7.1.3 DoD plans

5.2.2.8 Process/lot fraction defective

5.2.2.9 Mean or standard deviation of a process/lot

5.2.3 Rectifying inspection/auditing

5.2.3.1 Lot-by-lot sampling

5.2.3.2 Continuous production

5.2.3.3 Toward eliminating inspection

5.2.3.4 Mistake proofing

5.2.3.5 Gauge repeatability and reproducibility (R&R)

5.3 Off-line Quality Engineering Methods

5.3.1 Design of Experiments

5.3.1.1 Strategy of experimentation

5.3.1.2 Basic analysis techniques, analysis of variance (ANOVA)

5.3.1.3 Experimental principles: replication, randomization, and blocking

5.3.1.4 Factorial designs

5.3.1.5 Two-level factorial designs, blocking, and confounding

5.3.1.6 Fractional factorial designs

5.3.1.7 Random factors in experiments

5.3.1.8 Nested and split-plot designs

5.3.2 Regression

5.3.2.1 Simple linear regression models

5.3.2.2 Inference in simple linear regression

5.3.2.3 Residual analysis and model adequacy checking

5.3.2.4 Multiple linear regression model fitting

5.3.2.5 Inference in multiple regression

5.3.2.6 Model adequacy checking

5.3.2.7 Variable selection techniques, stepwise regression, and related methods

5.3.3 Response Surface Methodology

5.3.3.1 One factor at a time

5.3.3.2 Central composite design

5.3.3.3 Robust design

5.3.3.4 Control factor and noise factor

5.3.3.5 Cross array design

5.3.3.6 Taguchi method

5.4 Quality Management and Training

5.4.1 Lean Six Sigma

5.4.1.1 Customer focused quality

5.4.1.2 Defects per million opportunities (DPMO)

5.4.1.3 Process capability

5.4.1.4 Value stream mapping

5.4.1.5 Types of wastes

5.4.1.6 Business diagnostic

5.4.1.7 Decision making based on data

5.4.1.8 DMAIC

5.4.1.9 Define

5.4.1.10 Measure

5.4.1.11 Analyze

5.4.1.12 Improve

5.4.1.13 Control

5.4.1.14 DMADV

5.4.1.15 Define

5.4.1.16 Measure

5.4.1.17 Analyze

5.4.1.18 Design

5.4.1.19 Verify

5.4.2 Change Management

5.4.2.1 Building Support

5.5 Reliability Engineering

5.5.1 Fundamentals

5.5.1.1 Definition: reliability, availability, maintainability

5.5.1.2 Failure time distributions

5.5.1.3 Basic system configurations

5.5.1.4 Series systems

5.5.1.5 Parallel systems

5.5.1.6 K-out-of-n systems

5.5.1.7 Network systems

5.5.2 Reliability Testing

5.5.2.1 Burn-in testing

5.5.2.2 Demonstration testing

5.5.2.3 Acceptance testing

5.5.2.4 Accelerated testing

5.5.2.5 Degradation testing

5.5.3 Failure Analysis

5.5.3.1 Failure modes

5.5.3.2 Failure mechanisms

5.5.3.3 Fault tree analysis

5.5.3.4 Failure modes and effects analysis (FMEA)

5.5.4 Maintenance

5.5.4.1 Sensors and applications in maintenance

5.5.4.2 Preventative maintenance

5.5.4.3 Failure replacement

5.5.4.4 Condition-based maintenance

5.5.4.5 Group replacement

5.5.4.6 Maintenance and warranty

REFERENCES:

Introduction to Statistical Quality Control. Montgomery, D. C. Wiley, 7th Edition. 2013.

Introduction to Linear Regression Analysis. Montgomery, D. C., Peck, E. A., and Vining, G. G. John Wiley & Sons, 5th Edition. 2012.

Reliability in Engineering Design. Kapur, Kailash C. and Lamberson, Leonard R. John Wiley & Sons. 1977.

Design and Analysis of Experiments. Montgomery, D. C. Wiley, 8th Edition. 2012.

Applied Statistics and Probability for Engineers. Montogomery, D. C. and Runger, G. C. John Wiley and Sons, 6th Edition. 2014.

NIST/SEMATECH e-Handbook of Statistical Methods. www.itl.nist.gov/div898/handbook. 2013.

Implementing Six Sigma: Smarter Solutions Using Statistical Methods. Breyfogle III, Forrest W. Wiley. 2003.

Juran's Quality Handbook. Juran, J. M. and De Feo, Joseph A. McGraw Hill, 6th Edition. 2010.

Experiments: Planning, Analysis, and Parameter Design Optimization. Wu, C. F. J. and Hamada, M. John Wiley & Sons, 2nd Edition. 2009.

Reliability Engineering. Elsayed, E. A. John Wiley & Sons, 2nd Edition. 2012.

6 Ergonomics and Human Factors

Ergonomics and Human Factors as a field of research and practice is concerned with the design and analysis of equipment and devices that fit the human body and its cognitive abilities. The knowledge area includes contributions from anthropometry, statistics, psychology, physiology, biomechanics, industrial design, graphic design, operations research, and other disciplines. It is the study of designing equipment and devices that fit the human body and its cognitive abilities. The areas of emphasis are: Physical Ergonomics, Cognitive Ergonomics, and Organizational Ergonomics.

6.1 Ergonomic Basics

- 6.1.1 Focuses of ergonomics
- 6.1.2 Ergonomics and its areas of application in a work system
- 6.1.3 Ergonomic interventions
- 6.1.4 Effectiveness and cost effectiveness of ergonomics

6.2 Organizational and Social Aspects of System Design

- 6.2.1 Systems design methods for ergonomics (see Systems Design & Engineering)
- 6.2.2 Organizational aspects
- 6.2.3 Psychosocial factors
- 6.2.4 Litigation
- 6.2.5 Cross-cultural considerations

6.3 Anthropometric Principles in Workspace and Equipment Design

- 6.3.1 Basic body mechanics
- 6.3.2 Risk factors for musculoskeletal disorders
- 6.3.3 Designing for a population of users
- 6.3.4 Sources of human variability
- 6.3.5 Anthropometry and its uses in ergonomics
- 6.3.6 Principles of applied anthropometry in ergonomics
- 6.3.7 Application of anthropometry in design
- 6.3.8 Designing for everyone

6.4 Work Capacity and Fatigue

- 6.4.1 Muscles, structure, function, and capacity
- 6.4.2 Occupational biomechanics
- 6.4.3 Cardiovascular system
- 6.4.4 Respiratory system
- 6.4.5 Physical work capacity
- 6.4.6 Applied physiology in designing the workplace
- 6.4.7 Fitness for work

6.5 Design of the Thermal Environment

- 6.5.1 Fundamentals of human thermoregulation
- 6.5.2 Thermoregulatory mechanisms
- 6.5.3 Measuring the thermal environment
- 6.5.4 Work in hot climates
- 6.5.5 Work in cold climates

6.6 Design of Repetitive Tasks

- 6.6.1 Introduction to work-related musculoskeletal disorders
- 6.6.2 Injuries to the upper body at work
- 6.6.3 Tissue pathomechanics
- 6.6.4 Carpal tunnel syndrome
- 6.6.5 Lower and upper limbs

6.7 Design of Manual Handling Tasks

- 6.7.1 Anatomy and biomechanics of manual handling
- 6.7.2 Prevention of manual handling injuries in the workplace
- 6.7.3 Design of manual handling tasks
- 6.7.4 Lifting, carrying, and pushing
- 6.7.5 NIOSH lifting equation

6.8 Design for Standing and Sitting

6.8.1 Ergonomic approach to workstation design

6.8.2 Design for standing workers

6.8.3 Design for seated workers

6.8.4 Work surface design

6.8.5 Visual displays

6.8.6 Guidelines for the design of static work

6.8.7 Computer workstation design

6.9 Vision, Light, and Lighting

6.9.1 Vision and the eye

6.9.2 Measurement of light

6.9.3 Lighting design considerations

6.9.4 Visual fatigue, eyestrain, and near work

6.9.5 Psychological aspects of indoor lighting

6.10 Hearing, Sound, Noise, and Vibration

6.10.1 Sound and the ear

6.10.2 Measurement of sound

6.10.3 Hearing protection

6.10.4 Design of the acoustic environment

6.10.5 Noise control

6.10.6 Effects of noise on task performance

6.10.7 Non-auditory effects of noise on health

6.10.8 Vibration

6.11 Human Information Processing, Skill, and Performance

6.11.1 Information processing models

6.11.2 Cognitive systems

6.11.3 Problem solving

6.12 Displays and Controls

6.12.1 Human-centered design processes for interactive systems

6.12.2 Principles for the design of visual displays

6.12.3 Auditory displays

6.12.4 Design of controls

6.12.5 Combining displays and controls

6.13 Human-machine interaction, human error, and safety

6.13.1 Human error and equipment design

6.13.2 Mental workload in human machine interaction

6.13.3 Psychological aspects of human error

6.13.4 Characterizing human-machine interaction

6.13.5 Prevention of error in human-machine interaction

6.13.6 Accidents and safety

REFERENCES:

Introduction to Human Factors and Ergonomics for Engineers. Lehto, Mark R. and Landry, Steven J. CRC Press, 2nd Edition. 2013.

Fundamentals of Industrial Ergonomics. Pulat, Babur M. Waveland Press. 2nd Edition. 1997.

Engineering Psychology and Human Performance. Wickens, Christopher D., Hollands, Justin G., Banbury, S. and Parasuraman, R. Routledge, 4th Edition. 2016.

Introduction to Ergonomics. Bridger, R. CRC Press, 3rd Edition. 2008.

Kodak's Ergonomic Design for People at Work. Eastman Kodak Company. Wiley, 2nd Edition. 2004.

Occupational Biomechanics. Chaffin, Don B., Andersson, Gunnar B.J. and Martin, Bernard J. Wiley, 4th Edition. 2006.

An Introduction to Human Factors Engineering. Wickens, Christopher D., Lee, J., Gordon-Becker, S. and Liu, Y. Pearson, 2nd Edition. 2014.

7 Operations Engineering & Management

Operations Engineering and Management is an area of technical management dealing with the design and analysis of production and service processes. From an industrial engineering viewpoint this knowledge area employs tools and techniques to ensure business operations function efficiently, using as few resources as needed, and effectively in meeting customer requirements.

7.1 Operations Planning

7.1.1 Life cycles

7.1.1.1 Product

7.1.1.2 Service

7.1.1.3 Process

7.1.2 Forecasting

7.1.2.1 Methods/models

7.1.2.2 Trend based

7.1.2.3 Seasonal series

7.1.3 Aggregate planning

7.1.4 Market analysis

7.2 Project Management

7.2.1 Project as a network

7.2.2 Critical path analysis

7.2.3 PERT

7.2.4 Managing multiple projects

7.2.4.1 Constrained resources

7.3 Planning and Control for Manufacturing Systems/Projects

7.3.1 Scheduling

7.3.1.1 Master scheduling

7.3.1.2 Capacity

7.3.1.3 Leveling load demand

7.3.2 Sequencing

7.4 Production Scheduling

- 7.4.1 Job shops
- 7.4.2 Continuous flow
- 7.4.3 Just-in-time/Kanban
- 7.4.4 Level loading
- 7.4.5 Work schedules/personnel scheduling

7.5 Inventory Management & Control

- 7.5.1 Known demand
- 7.5.2 Uncertain demand
- 7.5.3 Make to order
- 7.5.4 Make to assembly
- 7.5.5 Make to stock

7.6 Capacity Management

- 7.6.1 Labor
- 7.6.2 Equipment
- 7.6.3 Materials
- 7.6.4 Demand management (voice of customer)
- 7.6.5 Throughput

7.7 Materials Requirements Planning

- 7.7.1 Master production schedule
- 7.7.2 Explosion calculus
- 7.7.3 Lot synergy
- 7.7.4 Multiline optimization
- 7.7.5 Enterprise resource planning

7.8 Purchasing/Supply Chain

- 7.8.1 (See Supply Chain Management)

7.9 Maintenance Management & Control

- 7.9.1 Maintenance models
- 7.9.2 Total productive maintenance

7.10 Organizational Issues (See Engineering Management)

7.11 Product Lifecycle Management

- 7.11.1 Aftermarket
- 7.11.2 Spares
- 7.11.3 Repairs
- 7.11.4 Warranty/non-warranty/good-will

7.12 Operational Metrics

- 7.12.1 Cost
- 7.12.2 Quality
- 7.12.3 Service level
- 7.12.4 Delivery
- 7.12.5 Productivity
- 7.12.6 Throughput
- 7.12.7 Plan effectiveness

REFERENCES:

Service Operations Management: Improving Service Delivery. Johnston, R., Clark, C. and Shulver, M. Pearson, 4th Edition. 2012.

Production and Operations Analysis. Nahmias, S. and T. Lennon Olsen. Waveland Press, Inc., 7th Edition. 2015.

Operations Management: Creating Value Along the Supply Chain. Russell, Roberta S. and Taylor, Bernard W. John Wiley & Sons, 7th Edition. 2011.

8 Supply Chain Management

Supply Chain Management (SCM) covers the movement, production, and storage of raw materials, work-in-process inventory, finished goods, and services from point of origin to point of consumption or use. Suppliers, manufacturers, intermediaries, stores, and service enterprises are involved in delivery of products and services to end customers in a supply chain.

8.1 Supply Chain Management Fundamentals

- 8.1.1 Supply chain management processes
- 8.1.2 Make/buy analysis
- 8.1.3 Adding value to organizations
- 8.1.4 Importance of aligning supply chain strategy with corporate strategy
- 8.1.5 Supply chain risk management strategies
- 8.1.6 Assessment and measurement of effectiveness of supply chains
- 8.1.7 Fundamentals of green supply chain initiatives

8.2 Building Competitive Operations, Planning, and Logistics

- 8.2.1 Dynamics within the supply chain to optimize performance and increase profitability
- 8.2.2 Designing agility into a supply chain
- 8.2.3 Lean principles in a supply chain
- 8.2.4 Assessing the value of demand
- 8.2.5 Reducing complexity in demand planning
- 8.2.6 Establishing collaborations to replace or improve demand estimates

8.2.7 Including supply chain factors in product design

8.2.7.1 Cost

8.2.7.2 Packaging

8.2.8 Aligning distribution and transportation options with supply chain strategy

8.2.9 3PL and 4PL service providers

8.2.10 Supply chain network design

8.2.10.1 Tiers

8.2.10.2 Number, size, and location of facilities

8.3 Reverse Logistics

8.3.1 Shared-resource, closed-loop systems

8.3.2 Capacity utilization from multi-directional product flow

8.4 Managing Product Flow

8.4.1 Inventory control methodologies (see Operations Engineering & Management)

8.4.2 Material handling systems

8.4.3 Work sourcing management

8.4.4 Transportation management

8.4.4.1 Mode/carrier selection

8.4.4.2 Consolidation

8.4.4.3 Vehicle routing

8.5 Managing Customer Relationships

8.5.1 Customer stratification based on their profiles and needs

8.5.2 Understanding customer loyalty and lifetime value of a customer

8.5.3 Establishing measures of customer satisfaction

8.5.4 Supplier support and oversight

8.5.5 Managing Supplier Relationships

8.5.6 Insourcing vs. outsourcing decisions

8.5.6.1 On-shore

8.5.6.2 Off-shore

8.5.7 Strategic importance of purchasing and supplier relationships

8.5.8 Supplier scorecard systems

8.5.9 Managing the supplier lifecycle

8.5.9.1 Supplier selections

8.5.9.2 Contracting

8.5.9.3 Onboarding

8.5.9.4 Order-to-cash

8.5.9.5 Decommissioning a supplier

8.5.10 Customer data

8.5.10.1 Service performance

8.5.10.2 Increasing value to suppliers and customers

8.5.11 Selection of and understanding Tier 2,3, etc. suppliers

8.5.12 Supplier risk management

REFERENCES:

Supply Chain Management Best Practices. Blanchard, David. John Wiley & Sons, 2nd Edition. 2010.

Supply Chain Management: Processes, Partnerships, Performance. Lambert, Douglas M. Supply Chain Management Institute, 3rd Edition. 2008.

Supply Chain Management for Engineers. Huang, Samuel H. CRC Press. 2013.

Designing and Managing the Supply Chain. Simchi-Levi, David, Kaminsky, Philip., and Simchi-Levi, Edith. McGraw Hill, 3rd Edition. 2008.

Supply Chain Management: Strategy, Planning, and Operations. Chopra, Sunil, and Meindl, Peter. Pearson, 6th Edition, 2015.

Supply Chain Engineering: Models and Applications. Ravindran, A. Ravi, and Warsing, Donald. CRC Press, 2012.

Supply Chain Science. Hopp, Wallace. Waveland Press, 2011.

Supply Chain Logistics Management. Bowersox, Donald, Closs, Donald., and Cooper, Bixby. McGraw Hill, 4th Edition. 2012.

Managing Closed-Loop Supply Chains. Flapper, Simme Douwe., van Nunen, Jo, can Wassenhove, Luk N (Editors). Springer, 2005.

Introduction to Logistics Systems Management. Ghiani, Gianpaolo, Laporte, Gilbert., Musmanno, Roberto. John Whiley & Sons, 2nd Edition, 2013.

A Taxonomy for Supply Chain Management Literature. Capar, Ismail, Ulengin, Fusun, Reisman, Arnold. 2004. Available at SSRN: http://ssrn.com/abstract=531902 or http://dx.doi.org/10.2139/ssrn.531902.

9 Engineering Management

Engineering Management is a focused area of management dealing with the application of engineering principles to business practice. Whereas Operations Engineering and Management focuses on the design and analysis of production and service processes, Engineering Management deals with the technical business side of the organization.

9.1 Customer Focus

9.1.1 Needs identification and anticipation

9.1.2 Market product strategy

9.1.3 Fundamentals of customer relationship management

9.1.4 Quality function deployment

9.2 Leadership, Teamwork, and Organization

9.2.1 Leadership

9.2.2 Organizational structure and development

9.2.3 Teamwork

9.2.4 Communication

9.2.5 Internal corporate culture and external global culture

9.2.6 Management

9.3 Shared Knowledge Systems

9.3.1 Systems planning, design, and justification

9.3.2 Systems development

9.3.3 Infrastructure of a shared knowledge system

9.4 Business Processes

9.4.1 Product/process development

9.4.2 Process management and improvement (see Quality & Reliability Engineering)

9.4.3 Research and development

9.4.3.1 Technology management

9.4.4 Manufacturing

9.4.5 Transactional business processes

9.4.6 Customer support

9.5 Resource and Responsibility

9.5.1 Resources

9.5.2 Organizational responsibilities

9.5.3 Ethics in the practice of engineering management

9.6 Strategic Management

9.6.1 Vision and mission

9.6.2 Environmental scanning

9.6.3 Organizational assessment

9.6.4 The planning process

9.6.5 Goals, objectives, targets, and measures

9.6.6 Strategic planning

9.6.7 Plan implementation

9.6.8 Monitoring and evaluating progress

9.7 Human Resource Management

9.7.1 Human capital and technical competency management

9.7.2 Motivation theory and practice

9.7.3 Learning, education, training, and development

9.7.4 Performance management

9.7.5 Compensation management

9.7.5.1 Elements of compensation

9.7.5.2 Job analysis

9.7.5.3 Job evaluation

9.7.5.4 Incentive systems

9.7.5.5 Labor contracts

9.8 Project Management

9.8.1 Work breakdown structure of complex activities and form into an integrated plan

9.8.2 Project schedules/resource allocation

9.8.3 Cost estimating (see Engineering Economic Analysis)

9.8.4 Risk analysis of project plans and outcomes

9.9 Organizational Level Performance Management

9.9.1 Balanced scorecard

9.9.2 Productivity

9.9.3 Quality

9.9.4 Efficiency

9.9.5 Effectiveness

9.9.6 Safety

9.9.7 Customer satisfaction

9.9.8 Financial

REFERENCES:

Managing Engineering and Technology. Morse, Lucy C. and Bobcock, Daniel L. Prentice Hall, 6th Edition. 2013.

10 Safety

Occupational Safety Engineering addresses the origins of workplace accidents, regulations, and management practices towards mitigating hazard exposures, preventing harm, and reducing liability. Safety engineering also addresses methods and measures for recognizing and controlling workplace physical hazards, as well as approaches for dealing with accidents and facilitating recovery.

10.1 Perspective and Overview

- 10.1.1 History of safety and health movement
- 10.1.2 Definition of hazards and accident statistics
- 10.1.3 Theories of accident causation
- 10.1.4 Effects on global competition on safety and health practice and regulations

10.2 USA Laws and Regulations

- 10.2.1 Product safety and liability (safety in the courtroom)
- 10.2.2 Consumer product safety commission
- 10.2.3 Workers' compensation
- 10.2.4 OSHA standards and liability
- 10.2.5 OSHA record keeping system
- 10.2.6 Hazard communication standard (DOT regulations)

10.3 Hazard Recognition, Evaluation, and Control

- 10.3.1 Mechanical hazards and machine safeguarding
- 10.3.2 Fall hazards, acceleration, and impacts
- 10.3.3 Thermal stress
- 10.3.4 Noise and vibration hazards
- 10.3.5 Electrical hazards
- 10.3.6 Fire hazards and protection
- 10.3.7 Industrial hygiene and confined spaces
- 10.3.8 Radiation hazards, bloodborne pathogens, and bacterial hazards
- 10.3.9 Nanotechnology

10.4 Safety and Health Management

10.4.1 Ethics and safety

10.4.2 Emergency planning

10.4.3 Accident investigation and reporting

10.4.4 Corporate safety culture and behavior-based safety programs

10.4.5 Risk assessment/hazard analysis

10.4.5.1 Preliminary hazard analysis

REFERENCES:

Safety and Health for Engineers. Brauer, R. L. Van Nostrand Reinhold. 1990.
Occupational Safety and Health for Technologists, Engineers, and Managers. Goetsch, D. Prentice-Hall, 8th Edition. 2015.

System Safety Engineering and Risk Assessment. Bahr, Nicholas J. Taylor and Francis. 1997.

Engineering a Safer World – Systems Thinking Applied to Safety. Leveson, Nancy. The MIT Press. 2011.

Standard Practice for Systems Safety (MIL-STD-882D). US DOD. 2000.

11 Information Engineering

Information Engineering is an approach to planning, generating, distributing, analyzing, and using collections of data in systems to facilitate decision making and business communication.

11.1 Differentiating Data and Information

- 11.1.1 Data types

11.2 Systems Concepts

- 11.2.1 Number systems/codes
- 11.2.2 Computer organization
- 11.2.3 Servers and virtual machines (VM)
- 11.2.4 Data centers
- 11.2.5 Network basics
- 11.2.6 ERP architectures
- 11.2.7 Workflow management systems
- 11.2.8 Web and mobile applications
- 11.2.9 Content management systems (CMS)
- 11.2.10 N-tier architectures
- 11.2.11 Web service architectures
- 11.2.12 Cloud computing and service architectures
- 11.2.13 Ecommerce system architectures
- 11.2.14 Systems integration concepts

11.3 Information Requirements for Organizations

- 11.3.1 Classification of information
- 11.3.2 Management requirements
- 11.3.3 Decision making requirements
- 11.3.4 Operations requirements
- 11.3.5 Eliciting and gathering requirements
- 11.3.6 Usability and accessibility requirements

11.4 Designing Information Outputs

- 11.4.1 Filtering
- 11.4.2 Key variable reporting
- 11.4.3 Monitoring
- 11.4.4 Modeling
- 11.4.5 Interrogative
- 11.4.6 Strategic decision center
- 11.4.7 Usability concepts
- 11.4.8 Data visualization concepts
- 11.4.9 Designing dashboards

11.5 Data Processing Overview

- 11.5.1 Data processing resources used in information systems
- 11.5.2 Organizing data processing resources
- 11.5.3 Cloud and data center processing concepts
- 11.5.4 Big data processing concepts

11.6 Data Base Concepts

- 11.6.1 Application vs. data base processing
- 11.6.2 Data base management systems
- 11.6.3 SQL – language, joins, filters, sorting, aggregating, grouping, union/intersection/difference, ranking

11.7 Logical Data Organization

- 11.7.1 Trees
- 11.7.2 Relational
- 11.7.3 Star schema/data cube/ multidimensional model
- 11.7.4 NoSQL models
- 11.7.5 Data sharing models - CSV, XML, JSON

11.8 Physical Data Organization

- 11.8.1 Computer storage media
- 11.8.2 Pointers, chains, rings
- 11.8.3 Types of data structures: lists, dictionaries, queues, stacks, hash tables

11.9 Storage and Processing

- 11.9.1 Sequential data organization
- 11.9.2 Direct data organization
- 11.9.3 Data file classification
- 11.9.4 File media and file organization
- 11.9.5 File design
- 11.9.6 Replication and distribution
- 11.9.7 Backup and recovery

11.10 System Analysis

- 11.10.1 Systems development methodology for information systems
- 11.10.2 Determining the information system demand
- 11.10.3 Requirements modeling
- 11.10.4 Data and process modeling
- 11.10.5 Object modeling
- 11.10.6 Development strategies
- 11.10.7 UML and other common diagramming tools in analysis

11.11 System Design

- 11.11.1 Development of specifications to meet demand
- 11.11.2 Design process
- 11.11.3 Data design
- 11.11.4 System architecture design
- 11.11.5 UML and other common diagramming tools in design

11.12 System Evaluation and Justification

11.12.1 Obtaining equipment proposals

11.12.2 Obtaining software proposals

11.12.3 Evaluation of proposals

11.12.4 Acquisition considerations

11.13 Controls

11.13.1 Control points for reliable data processing

11.13.2 Security controls

11.13.3 Encryption

11.14 Forms, Programs, and Procedures

11.14.1 Forms/reports design

11.14.2 Program specifications

11.14.3 Programming techniques

11.15 System Implementation

11.15.1 Training and education

11.15.2 System testing

11.15.3 System conversion

11.15.4 Implementation follow-up

11.16 Management Considerations for the Information System

11.16.1 Maintenance

11.16.2 Auditing

11.16.3 Project management of information systems and software projects

11.16.4 Managing change

11.16.5 I.T. governance

11.17 Data Analytics

11.17.1 Data preparation

11.17.2 Feature identification and evaluation

11.17.3 Model evaluation

11.17.4 Descriptive analytics
11.17.5 Clustering models
11.17.6 Classification models
11.17.7 Predictive analytics
11.17.8 Prescriptive analytics

REFERENCES:

Software Engineering. Sommerville, I. Pearson Education, Inc, 19th Edition. 2016.

Requirements Engineering and Management for Software Development Projects. Chemuturi, Murali. Springer. 2013.

The Unified Modeling Language User Guide. Booch, G., Rumbaugh, J., and Jacobson, I. Pearson, 2nd Edition. 2005.

Design of Industrial Information Systems. Boucher, Thomas O. and Yalcin, Ali. Elsevier. 2006.

Fundamentals of Database Systems. Elmasri, R., Navathe, S.B. Addison-Wesley Longman, Inc., 7th Edition. 2016.

Management Information Systems: Managing the Digital Firm. Laudon, K.C. and Laudon, J.P. Pearson Education, Inc., 14th Edition. 2016.

Data Mining and Business Analytics with R. Ledolter, J., Wiley. 2013.

Python Machine Learning. Raschka, S., Mirjalili, V. Packt, 2nd Edition. 2017.

System Architecture. Burd, S. 8th Edition. 2018.

Enterprise Integration and Information Architecture: A Systems Perspective on Industrial Information Integration. Xu, L. CRC Press, 1st Edition. 2015.

Information Systems: What Every Business Student Needs to Know, Mallach, E. Chapman & Hall. 2015.

Health Information Exchange: Navigating and Managing a Network of Health Information Systems. Dixon, B. Academic Press, 1st Edition. 2016.

12 Design and Manufacturing Engineering

Design and Manufacturing Engineering focuses on tools and techniques to conceptualize, engineer, produce, and qualify physical products across feature-scales, production quantities, and application domains. From an industrial engineering viewpoint, this knowledge area is concerned with the development, optimization, and standardization of methods to transform raw materials into functional products to satisfy the applications' and stakeholders' requirements in the most time and cost-efficient manner.

12.1 Engineering Design

- 12.1.1 Product design methodology (see Product Design and Development knowledge area)
- 12.1.2 Dimensions, tolerances, limits, and fits
- 12.1.3 Computer aided design (CAD)
- 12.1.4 Physical modeling and prototyping
- 12.1.5 Design for X methodologies (design for machining, design for additive manufacturing, design for assembly, design for quality, etc.)
- 12.1.6 Other important considerations in product, process, and systems design – sustainability, legal, and ethical issues

12.2 Fundamentals of Materials

- 12.2.1 Types of engineering materials: metals, polymers, ceramics, and composites
- 12.2.2 Atomic and crystalline structure
- 12.2.3 Mechanical properties of materials
- 12.2.4 Physical properties of materials: thermal, electrical, and biological

12.3 Solidification-based Manufacturing Processes

- 12.3.1 Metal solidification, fluid flow, and heat transfer
- 12.3.2 Metal casting: expendable and permanent mold processes
- 12.3.3 Design for metal casting
- 12.3.4 Casting quality and inspection methods
- 12.3.5 Polymer processing: thermoplastics, thermosets, and polymer-matrix composites processing
- 12.3.6 Design for polymer processing
- 12.3.7 Quality considerations for processed polymer parts

12.4 Material Removal Processes

- 12.4.1 Theory of metal cutting
- 12.4.2 Conventional machining processes: turning, milling, drilling, and related operations and tools
- 12.4.3 Abrasive machining processes
- 12.4.4 Non-traditional machining processes
- 12.4.5 Machinability and quality considerations
- 12.4.6 Design for machining

12.5 Forming-based Processes

- 12.5.1 Fundamentals of metal forming
- 12.5.2 Bulk deformation processes: rolling, forging, extrusion, and related operations
- 12.5.3 Sheet metal working processes
- 12.5.4 Design for metal forming
- 12.5.5 Quality considerations

12.6 Particulate Processing

- 12.6.1 Characterization of engineering powders
- 12.6.2 Powder metallurgy
- 12.6.3 Ceramics processing
- 12.6.4 Design and quality considerations

12.7 Joining Processes

12.7.1 Welding: fusion and solid-state processes

12.7.2 Brazing, soldering, adhesive bonding, and related operations

12.7.3 Design and quality considerations

12.8 Additive Manufacturing (AM)

12.8.1 Fundamentals of AM

12.8.2 Categories and principles or AM processes

12.8.3 Design and material considerations in AM

12.8.4 Economics of AM

12.8.5 Hybrid AM: integration with traditional manufacturing processes

12.9 Biomedical Manufacturing (BM)

12.9.1 Fundamentals and categories of BM

12.9.2 Design and material considerations in BM

12.9.3 Principles of BM processes for polymer devices

12.9.4 Principles of BM processes for metal implants

12.9.5 Principles of BM processes for polymer scaffolds

12.9.6 Principles of BM processes for bioink constructs

12.9.7 Regulatory and economic considerations in BM

12.10 Micro and Nano-scale Manufacturing

12.10.1 Fundamentals of scaling

12.10.2 Deposition processes

12.10.3 Etching processes

12.10.4 Doping and surface modification

12.10.5 Lithography processes

12.10.6 Surface and wet bulk micromachining

12.10.7 LIGA

12.10.8 Scanning probe-based processes

12.10.9 Self-assembly processes

12.10.10 Economic considerations

12.11 Manufacturing Planning

- 12.11.1 Process planning
- 12.11.2 Group technology and product families
- 12.11.3 Computer aided manufacturing (CAM)
- 12.11.4 Concurrent engineering
- 12.11.5 Metrology: measurement and inspection
- 12.11.6 Quality control and assurance
- 12.11.7 Lean manufacturing and Six Sigma
- 12.11.8 Cost estimation and economics of manufacturing

12.12 Manufacturing Systems

- 12.12.1 Automation and systems integration
- 12.12.2 Numerical control
- 12.12.3 Robotics
- 12.12.4 Production and assembly lines
- 12.12.5 Production systems, planning, and control
- 12.12.6 Flexible manufacturing systems
- 12.12.7 Computer integrated manufacturing (CIM)
- 12.12.8 Cellular manufacturing
- 12.12.9 Industry 4.0: digital and smart manufacturing

REFERENCES:

Computer-Aided Manufacturing. Chang, Tien-Chien, Wysk, Richard A. and Wang, Hsu-Pin. Prentice Hall, 3rd Edition. 2006.

Computer-Integrated Design and Manufacturing. Bedworth, David D., Henderson, Mark R. and Wolfe, Philip M. McGraw-Hill. 1991.

Engineering Design: A Practical Guide. Ogot, Madara and Kremer, Gül. Trafford Publishing. 2004.

Engineering Design. Dieter, George E. and Schmidt, Linda C. McGraw-Hill, 5th Edition. 2012.

Fundamentals of Microfabrication and Nanotechnology. Madou, Marc J. CRC Press, 3rd Edition. 2011.

Fundamentals of Modern Manufacturing: Materials, Processes, and Systems. Groover, Mikell P. Wiley, 6th Edition. 2015.

Manufacturing Engineering and Technology. Kalpakjian, Serope and Schmid, Steven R. Pearson, 7th Edition. 2014.

Product Design for Manufacture and Assembly. Boothroyd, Geoffrey, Dewhurst, Peter and Knight, Winston A. CRC Press, 3rd Edition. 2010

13 Product Design & Development

Product Design and Development is the efficient and effective generation and development of ideas through a process that leads to new products. From an industrial engineering knowledge view, it is the processes and analysis employed supporting efficient decision-making during Product Design and Development.

13.1 Design Process

13.1.1 State of the art

13.1.2 Identify need

13.1.3 Conceptualization

13.1.4 Feasibility analysis

13.1.5 Production

13.1.6 Product life cycle

13.2 Design Process Steps

13.2.1 Business strategy

13.2.2 Identification of need

13.2.2.1 Technology development

13.2.2.2 Proposal

13.2.2.3 Capture

13.2.3 Definition of a problem

13.2.3.1 Statement of requirements

13.2.4 Gathering of information and data

13.2.5 Benchmarking

13.2.5.1 Competitive intelligence

13.2.5.2 Intellectual property

13.2.6 Conceptualization

13.2.7 Evaluation

13.2.7.1 Analysis of design

13.2.7.2 Decision making

13.2.7.3 Trade studies

13.2.7.4 Weighing and judging

13.2.7.5 Quality function deployment (QFD)

13.2.8 Communication of the design

13.3 Design Project

13.3.1 Gating process

13.3.2 Feasibility study

13.3.3 Preliminary design

13.3.3.1 Internal interfaces

13.3.3.2 External interfaces

13.3.4 Detailed design

13.3.5 Verification and Test

13.3.5.1 Demonstration builds

13.3.5.2 Systems test

13.3.5.3 Operational test

13.3.5.4 Audits

13.3.6 Planning for manufacture/production

13.3.6.1 Factory planning

13.3.6.2 Supply chain

13.3.7 Planning for distribution

13.3.8 Planning for use

13.3.9 Operations and support

13.3.10 Planning for retirement

13.4 Economic Decision-Making/Cost Evaluation

13.4.1 Life cycle analysis

13.5 Planning and Scheduling

13.5.1 Planning for manufacturing

13.5.2 Project planning

13.6 Risk and Opportunity Management

13.7 Metrics for Design and Development

13.8 Program Leadership, Management, and Control

13.8.1 Project start-up

13.8.2 Plans/schedules

13.9 Design for Manufacturability

13.9.1 How manufacturability can influence design

13.9.2 Methods and procedures for production activity

13.9.3 Work instruction/documentation for production

13.9.4 Manufacturing process optimization

13.10 Design for Cost

13.11 Design for Six Sigma

13.11.1 I2DOV process

13.11.1.1 Invent

13.11.1.2 Innovate

13.11.1.3 Develop

13.11.1.4 Optimize

13.11.1.5 Verify

13.11.2 CDOV process

13.11.2.1 Concept design

13.11.2.2 Design development

13.11.2.3 Optimize

13.11.2.4 Verify

REFERENCES:

Product Design and Development. Ulrich, Karl T. and Eppinger, Steven D. McGraw-Hill/Irwin, 5th Edition. 2011.

Production and Operations Analysis with Student CD. Nahmias, Steven. McGraw-Hill/Irwin, 5th Edition. 2004.

Design Structure Matrix Methods and Applications (Engineering Systems). Eppinger, Steven D., Browning, Tyson R. The MIT Press. 2012.

14 Systems Design & Engineering

Systems Design and Engineering deals with integrating aspects of other engineering disciplines, ensuring that all likely aspects of a project or system are considered and efficiently integrated together. This area contains a strong cross coupling to industrial engineering. Refer to the Systems Engineering Body of Knowledge (SEBoK) for additional details.

14.1 Mission Engineering

14.1.1 Articulation and analysis of purpose for the system

14.2 Requirements Analysis and Allocation

14.2.1 Requirements statements

14.2.2 Obtaining requirements

14.2.3 Derived and allocated requirements

14.2.4 Requirements analysis

14.2.5 System specification

14.2.6 Interfaces

14.2.6.1 Internal

14.2.6.2 External

14.2.7 Value engineering

14.2.8 Sensitivity analysis

14.2.9 Trade studies

14.3 System Architecting

14.3.1 Architecture descriptions

14.3.2 Steps in system architecting

14.3.3 Fundamental design choices in constructing a system

14.3.4 80-20 rule

14.4 Subsystem Design

14.4.1 Detailed design of elements

14.4.2 Interface control

14.5 System Construction

14.5.1 Hardware, software, human components

14.5.2 Integration

14.6 Verifying and Validating Requirements

14.6.1 Verification program components

14.6.1.1 Requirements

14.6.1.2 Planning

14.6.1.3 Success criteria

14.6.1.4 Reports

14.6.1.5 Compliance

14.6.2 Test and evaluation

14.6.3 Design of experiments (DOE)

14.6.4 Satisfaction of all user and customer requirements

14.7 Design Iteration

14.7.1 Refinement

14.7.2 Convergence

14.7.3 Robust systems

14.8 Product and Services Design

14.9 Role of Models in Systems Design Process

14.9.1 Model vs. actual system

14.9.2 System objectives/user input

14.9.3 Analyzing model output for system design decisions

14.10 Completing the Systems Engineering Process

14.10.1 Establishing a systematic and repeatable process

14.10.1.1 Technical performance measures

14.10.1.2 Technical data management

14.10.1.3 Configuration management

14.10.2 Life cycle costing

14.10.2.1 Cost estimation models and techniques

14.10.2.2 Design, development, manufacturing, operations, and supportability

14.10.2.3 Cost effective trade-offs to customer problems (see Engineering Economic Analysis knowledge area)

14.10.3 Limitation of humans in systems

14.10.4 Risk analysis

14.10.4.1 Cost, schedule, and performance risk

14.10.5 Concurrent engineering

14.10.6 Integrated logistics support

14.10.6.1 Interoperability and harmonious system operation

14.10.7 Reliability, maintainability, availability (see Quality and Reliability Engineering knowledge area)

14.10.8 Quality assurance and management (see Quality and Reliability Engineering knowledge area)

14.10.9 Specialty engineering

14.10.10 Preplanned product improvement

14.10.11 Training

14.10.12 Documentation

14.10.13 Production

14.10.14 Installation

14.10.15 Operations and maintenance

14.10.16 Operations evaluation/reengineering

14.10.17 Systems engineering management

14.10.17.1 Planning

14.10.17.2 Organizing

14.10.17.3 Directing

14.10.17.4 Monitoring

REFERENCES:

Guide to the Systems Engineering Body of Knowledge (SEBoK). Pyster, Art and Olwell, David. The Trustees of the Stevens Institute of Technology. 2013.

Systems Engineering and Analysis. Blanchard, Benjamin S. and Fabrycky, Wolter J. Pearson, 5th Edition. 2011.

Systems Engineering: Principles and Practice. Kossiakoff, Alexander, Sweet, William., Symour, Sam., and Biemer, Steven M. John Wiley & Sons, 2nd Edition. 2011.

Essentials of Project and Systems Engineering Management. Eisner, Howard. John Wiley & Sons, 3rd Edition. 2008.

Requirements Engineering. Hull, M. Elizabeth C., Jackson, Kenneth, and Dick, Jeremy. Springer, 2nd Edition. 2004.

The Engineering Design of Systems: Models and Methods, Wiley Series in Systems Engineering. Buede, Dennis M., and Miller, W. Wiley-Interscience, 3rd Edition. 2016.

INCOSE Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities. Walden, D. and Roedler, G. John Wiley, 4th Edition. 2015.